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ADP012407

TITLE: Recent Advances in Protective Clothing Technology

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TITLE: Blowing Hot and Cold: Protecting Against Climatic Extremes [Souffler le chaud et le froid: comment se proteger contre les conditions climstiques extremes]

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Recent Advances in Protective Clothing Technology

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SUMMARY

Several recent advances in protective clothing technology are presented. The advances are related to floatation, thermal protection, anti-gravity protection, and the integration of protective clothing and equipment, which are specific areas of technical expertise for Mustang Survival Corporation.

INTRODUCTION

Mustang Survival [1] is a privately owned Canadian corporation founded in 1967 by Irving Davies. Mustang Survival's early success was related to the design and manufacture of *flotation* and *hypothermia* protective clothing. Over the last decade, the corporation has expanded into the areas of *active cooling*, *anti-gravity* protection, and the *integration* of protective clothing and equipment.

Mustang Survival is rather unique in the clothing industry, in that, it has research and development (R&D) capabilities. In addition to assisting the corporation' industrial, recreational, and military product lines, R&D is contracted externally. This paper details some of the more recent advances in clothing technology made by Mustang Survival and provides their relative pros and cons.

TECHNOLOGIES

Flotation

Life Preserver/Survival Vest (LP/SV)

The Life Preserver / Survival Vest (Mustang MSV 971 LP/SV series) has been in use with the Canadian Forces (CF) since the early 1990's. There are several variants of LP/SV configuration in use with NATO aircrew. In general, the LP is an inflatable device that provides 35 to 37 lbs (156 – 166 N) of buoyancy. The bladder is shaped like a conventional "horse-collar" design. The SV has many different pocket configurations.

Generally, the LP/SV is capable of consistently *self-righting* most aircrew unless it is worn in conjunction with immersion suits and/or anti-G garments, which trap large amounts of air or are inherently buoyant. *Self-righting* is the ability of a flotation device to turn an unconscious, immersed subject from a face down to a face up orientation. This potential safety concern exists with most aircrew immersion suit and LP/SV combinations. Recent advances we have made in flotation technology have attempted to address this particular performance issue.

Paper presented at the RTO HFM Symposium on "Blowing Hot and Cold: Protecting Against Climatic Extremes", held in Dresden, Germany, 8-10 October 2001, and published in RTO-MP-076.

NASA Life Preserver Unit (LPU)

In 1994, Mustang Survival developed the LPU used by NASA Space Shuttle Crewmembers (Figure 1). The LPU has been in-service with NASA since 1995. The shape of the current inflated LPU bladder is rather unconventional. It provides 129 lbs (576 N) of buoyancy, an unusually high amount.

The ability to *self-right* the crewmember was a key performance requirement of the NASA LPU design. The crewmember's inflated anti-G trouser can cause them to float horizontally on the surface of the water. This position can be very stable, whether on one's side, face up or face down. This makes inducing a moment of rotation around the lengthwise axis of the body, very difficult. It was also observed that the dangling backpack, which contains the crewmember's survival water ration, either aids or hinders self-righting. With the anti-G trouser deflated, self-righting is achieved. With the trouser deflated, the crewmembers' legs drop in the water and they no longer float in a stable horizontal position. The large volume of the front lobes, the overall shape of the inflated bladder, and method of anchoring to the body are keys to achieving self-righting.

The Shuttle crewmember's helmet has an anti-suffocation valve located near its base, which must remain above water. The current LPU has such a large inflated volume, in order to provide the unusually high amount of *freeboard* (defined as the distance between the water surface and lowest breathing cavity) required by Shuttle crewmembers. The LPU provides the wearer with improved field of vision, which seems to impart a feeling of being in greater control (Figure 2).

With such a large volume LPU, the crewmember's in-water *mobility* and ability to board a their single-person life raft becomes more difficult. Small stature crewmembers found boarding the raft in calm water with the inflated LPU to be either impossible or very difficult. In most cases, deflation of the LPU aided boarding. It was observed that the bladder bulk beneath and behind the crewmember's arms hindered the range of arm motion necessary to pull the nose of the partially inflated life raft underneath their posterior.

Figure 1 – Side view of current NASA LPU

Figure 2 – Front view of current NASA LPU

NASA Enhanced Life Preserver Unit (ELPU)

In 2001, Mustang Survival developed a prototype Enhanced Life Preserver Unit (ELPU) for NASA. The new ELPU design addressed the in-water mobility deficiency noted with the current in-service LPU when worn by small crewmembers.

Ultimately, the original LPU was re-shaped to improve mobility (Figure 3). This advance did not come easy! Numerous iterations of design and water testing were conducted. Initially we reduced the bulk of the bladder by a considerable amount, in order to try and improve arm mobility. But when we reduced bladder bulk beneath the arms, we lost critical freeboard and self-righting became less consistent. As we recovered flotation performance by increasing buoyancy in several key areas, we restricted mobility again! During testing with various subjects, each with their own custom-fit parachute harness, we noted performance differences attributable to variability of the LPU-to-body anchoring points.

A multitude of different bladder shapes was tested. The final solution involved "scalloping" or carving out regions of the bladder directly beneath and behind the wearer's arms (Figure 4). The ELPU design is about to undergo extensive evaluation and hence is not presently in-service with Shuttle crewmembers.

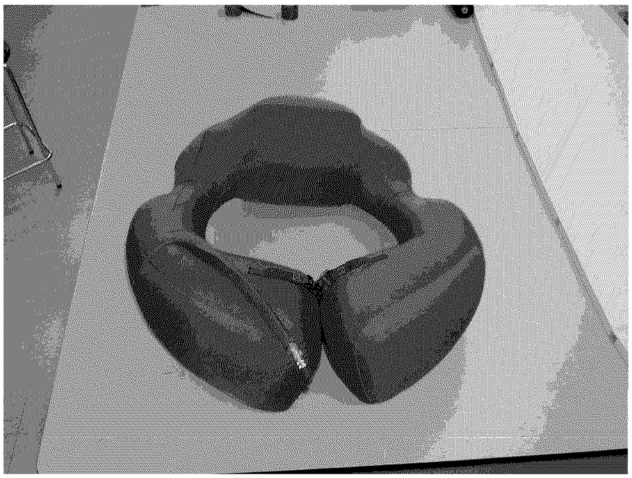

Figure 3 – Front view of prototype NASA ELPU

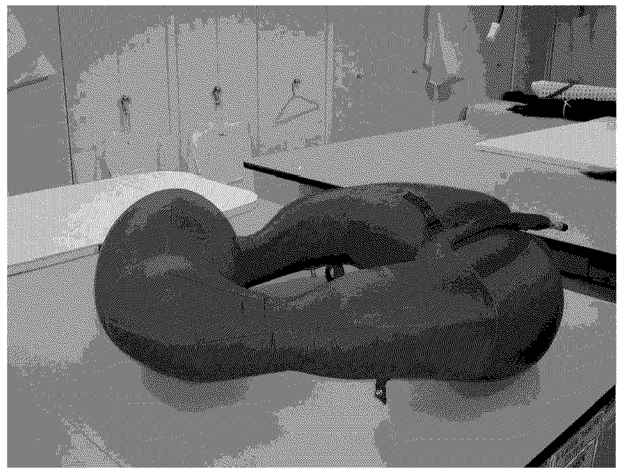

Figure 4 – Side view of prototype NASA ELPU

Advanced Life Preservers

The basic shape of the in-service NASA LPU design spawned several variants of inflatable LPUs that are now commercially available. Each LPU has subtle differences that make it perform with particular immersion suits. These variants are now worn by helicopter passengers transiting to and from oil/gas platforms offshore of Canada and the United States. The Canadian Forces have also investigated the performance of this helicopter LPU with several constant-wear aircrew anti-exposure coveralls.

Beware. The performance of any type of flotation device is very dependent on the immersion suit it is worn in conjunction with. *Self-righting* is not necessarily achieved with any subject, in any water condition and any form of immersion suit with such an LPU design. Secure anchoring of LPU to body and/or suit is one of the keys to achieving self-righting performance.

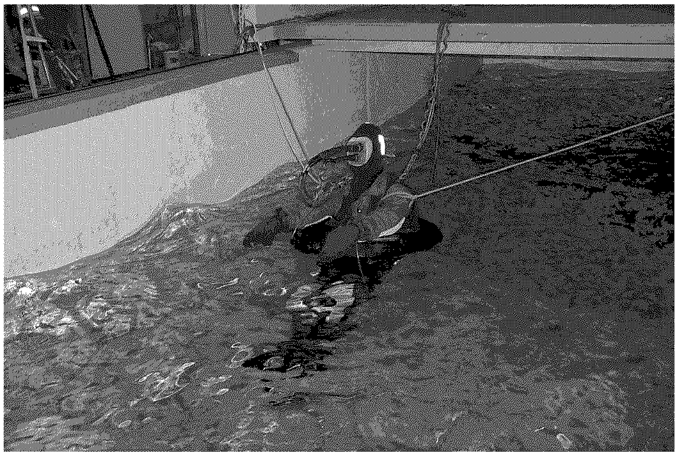

Figure 5 – Thermal manikin evaluation of MAC200 and advanced life preserver

The physical interactions between the human, suit, flotation device and environment are complex and even with the present body of knowledge in this subject area, it is extremely difficult, if not impossible, to understand these interactions via dynamic hydrostatic computer modeling. Mustang Survival is continually exploring many advanced life preserver concepts aimed at providing high freeboard, stability, ample field of vision, and self-righting with immersion suits. There are likely potential benefits in terms of hypothermia protection that may be achieved by removing the torso from the water (Figure 5). This really should be investigated further.

Wind Blast - Life Preserver / Survival Vest

Mustang recently improved its LP/SV that is in use with the Canadian Forces. The advance addressed a deficiency noted during ejection testing at 600 knots. At this speed, items of survival equipment were at risk of being lost from the vest pockets. The LP bladder and cover were at risk of being stripped from their attachment points on the SV carrier. Displacement of the beaded LP inflation lanyard may also inadvertently inflate the LP.

Flaps and closure methods on the SV pockets were re-designed to prevent their loss of contents upon ejection. A protective cup and snap system was designed to stop the flow of forced air from entering the LP securing strap points at the base of the LP cover. An elasticized cover was added to protect the automatic inflation lanyard. The design changes to the LP/SV have been verified in actual ejection testing. The LP/SV is capable of integrating with an air-cooling vest and ballistic panel inserts meeting NIJ Level III.

Damage Tolerant Inflatable Personal Flotation Device

Another recent advance in personal flotation is our Damage Tolerant Inflatable PFD [2]. Due to multiple self-shifting bladders, this PFD can sustain limited puncture damage from snags, bullets and shrapnel yet remain inflated. Comprehensive ballistic testing of the PFD and its compressed gas inflation system is currently being conducted in conjunction with Pacific Body Armor of Kelowna, British Columbia, Canada and several other agencies.

Re-breather Hood

Two key factors in one's ability to egress from a water-ditched aircraft or submerged vessel are the ability to breathe and see [3]. In an attempt to address these, we designed a waterproof hood [4] that could be donned by simply pulling it overtop of one's head while in air. The hood is watertight and seals around the wearer's

neck. Air trapped within voids inside the hood is re-breathed for a limited duration. The hood has a flexible, transparent visor that assists vision by allowing the wearer to open their eyes and focus underwater.

Testing was conducted to determine gas exchange through the gas permeable hood while wearing the hood in air and to determine average underwater breathing times. The prototype hood is sitting on the shelf, awaiting some form of user interest.

Stretcher Evacuation

A system similar to the re-breather hood was designed for protecting the whole body. The prototype system was intended for evacuating stretcher-bound medevac patients from inside a water-ditched or submerged vessel. The system encloses the entire stretcher in a waterproof sack thus providing both short-term breathing and vision underwater as well as thermal protection and flotation at the water surface. Several waterproof zippers were provided for accessing the patient.

The waterproof sack had exhaust valves and the stretcher was equipped with three inflatable bladders. This combination allowed stretcher egress assistant(s) to vent air from the sack for the low buoyancy needed for underwater egress and to establish high buoyancy which brings them to the water surface in a stable floating position. The prototype system was also capable of self-righting. Once at the surface, the visor region could be unzipped to open the system for long-term breathing and patient access. In 1994, underwater egress of a stretcher-bound subject was demonstrated at Survival Systems Limited by the CORD Group of Dartmouth, Nova Scotia, Canada. The prototype has not received any interest since.

Thermal Protection

Mustang Survival has been experimenting with various approaches to providing thermal protection during immersion in cold water, particularly for users who need constant wear protection yet may be working hard and/or exposed to hot environments.

For the designer, providing protection against both environmental extremes with passive insulation is a daunting challenge, wrought with compromise. Typically, a minimum insulation level of 0.75 immersed clo is required for aircrew. This results in clothing with insulation of between 1.6 to 2.0 clo in still air. This is essentially backwards to the ideal, in which, insulation levels in water exceed those during normal wear in air.

If one is to view the ratio between a garment's immersed insulation (I_{imm}) and insulation in still air (I_{air}), a potentially meaningful index related to overall thermal protection is formed (i.e. $i = I_{imm} / I_{air}$). For a nude subject in still air, thermal insulation is about 0.8 clo [5]. Nude in still water, thermal insulation can drop as low as 0.06 immersed clo [6]. This example would equate to an index of only 0.08 (i.e. 0.06 / 0.8), which would be indicative of poor overall thermal protection. Typical aircrew immersion suits provide about 2.0 clo in still air and 0.75 immersed clo, which gives a slightly higher index in the order of 0.38. If we could provide a minimum of 0.75 immersed clo and the same level of insulation in still air, the index would near 1.0. The ideal, which would occur when immersed insulation exceeds insulation in air, would have an index greater than 1.0. We have a long way to go if we want to achieve such an ideal ratio of thermal insulation!

Immersion Suits

One of our immersion suit designs has attempted to address the compromise that must be made to achieve such insulation levels. We've attempted to minimize thermal insulation during normal wear by making waterproof vapour permeable suit that is more tolerant in terms of losing thermal insulation should highly probable suit leakage occur during immersion. Most in-service dry suits are known to be prone to leakage. On average, they lose forty percent of their insulation with one litre of leakage [7].

The design decision was made to allow small amounts of leakage via cuffs at the neck and wrists. Accepting leakage allowed us to design adjustable cuffs that could be worn loosely open yet tighten when required. Since the cuffs are less constrictive than typical latex cuffs, they are more comfortable and their openness allows for dissipation of air, saturated with perspiration, from inside the suit.

An unconventional zipper configuration was chosen as an alternate way to provide both donning/doffing and the ability to relief oneself via a single waterproof zipper. There is an aircrew (MAC200) and a marine variant (MSD900) of the suit available. Both suits are currently seeing extensive evaluation by numerous government agencies. On the aircrew version, the zipper forms a helix around the torso [8]. To-date the basic suit design has met with both user acceptance and dislike. In particular, the zipper and cuff configuration have met resistance with certain users; more "user-friendly" zipper designs have been developed.

In terms of immersion protection, thermal manikin testing indicates that this suit design can achieve 0.91 immersed clo in stirred water and 1.63 clo in air. This equates to an immersion protective index of 0.56 (i.e. 0.91/1.63).

Atmospheric Self-Inflating Immersion Suit

A higher level of insulation in the order of 1.0+ immersed clo is typically achieved by neoprene foam immersion suits and life rafts. Both approaches occupy a large storage volume and are not generally considered as portable or wearable.

In 1993, Mustang Survival developed a low volume, high insulation immersion suit [9]. We created a 1.0 immersed clo immersion suit that uses a compressible insulating medium packaged in waterproof bladders. Use of a compressible medium, allows one to significantly reduce suit volume via vacuum packaging. The prototype suit is configured into a wearable "fanny" package with a total volume and weight of 5.5 litres and 2.4 kg, respectively. Since the insulation is resilient it forces the suit to self-inflate automatically upon opening of the vacuum package, in a manner similar to military self-inflating sleeping mattresses. The suit is multi-segmented to minimize water absorption in case of damage. Although, the suit has not seen operational use, an inflatable mitt and hood based on this concept have.

Thermal Undergarments

Thermal undergarments or dry suit liners have also seen recent advancements. One variant is that of water vapour permeable foam [10,11,12]. Its advantage over traditional fibrous battings and fleece is that it is inherent buoyant, non-absorbing, and resists hydrostatic compression. This does result in a somewhat heavier and stiffer undergarment though.

We also developed an incompressible diver's undergarment that resists hydrostatic compression experienced in diving operatons. It uses a fibrous batting that is pre-compressed during undergarment manufacture, to reduce any subsequent loss of thickness due to hydrostatic compression it sees in use. The undergarment includes a layer of waterproof, vapour permeable fabric to prevent external suit leakage and condensed perspiration from penetrating the insulating fibers. Both these features help it retain its in-water insulation.

Undergarments, which are inflatable upon immersion, have also been investigated. While variable insulation undergarments may offer slight improvement to thermal comfort and protection, it will improve to the degree ultimately required. Passive forms of insulation will only take us so far towards our thermal protection goal.

Active Heating

In 1995, Mustang integrated fabric laminates containing anhydrous magnesium chloride into anti-exposure coveralls (MS-195), as a means of actively heating water that is trapped inside the garment during immersion in cold water. Upon immersion, water-activated valves opened allow liquid water a pathway to the inside of the fabric laminate. The liquid water was prevented from making direct contact with the thermo-chemical by the presence of a series of waterproof, water vapour permeable membranes. These membranes allowed water vapour to diffuse into the thermo-chemical and deliquese at a controlled rate. This approach prevented dangerous over-heating due to thermal runaway and retained chemical reactants and products to prevent contact with skin or eyes. The entire laminate was sealed in polyurethane-coated nylon, to prevent both liquid water and its vapour from sources such as high humidity, sweating, condensation, spray, and rain etc., from activating the thermo-chemical.

Testing on a thermal manikin demonstrated an increase in the suit's immersed thermal insulation due to active heating, whereas, limited testing on humans showed an insignificant thermal benefit. It was determined that heating the water trapped within this particular garment microenvironment reduced shivering intensity and hence the amount of metabolic heat production. We have not investigated thermo-chemical heating since.

Enhanced Personal Cooling

At present, if we provide the level of immersed insulation needed, active cooling is required during constant wear. Mustang Survival recently developed a prototype Enhanced Personal Cooling Garment (EC) which uses a different approach than existing AC or LC [13,14]. The garment contains a thin layer of water and is worn next to the skin. Evaporation of water from the bladder extracts heat from the skin and underclothing.

When worn beneath air-cooling vests, cooling is enhanced as airflow increases the rate of evaporation hence the rate of cooling. EC also has a passive cooling potential without airflow. Human testing of the enhanced personal cooling garment is discussed in Paper #17.

Integration

Smart Aircrew Integrated Life Support System (SAILSS)

The F-22 air-cooling vest (Figure 6) made by Mustang Survival is currently being investigated as a platform for SAILSS physiological sensors. The intent is to first integrate Mustang Survival's Enhanced Personal Cooling Garment technology with current air-cooling vests in conjunction with Titan System's Semcor Division. Conceptual approaches to integrating cooling, SAILSS and the Navy Combat Edge CSU-21/P counter pressure vest are also being considered at the present time.

Tactile Situation Awareness System (TSAS)

The F-22 air-cooling vest is also being used as the platform for attaching Tactile Situation Awareness System (TSAS) tactile sensors ("tactors"). Tactors present information on orientation to pilots and aircrew via tactile sensory receptors [15].

The F-22 air-cooling vest was found to apply pressure, which increased tactor-body contact. Generally, the United States Naval Aerospace Medical Research Laboratory (NAMRL) found tactor-body contact to be troublesome throughout their evaluation programs. To address this deficiency, Mustang Survival was tasked by NAMRL to develop a prototype garment that provided a platform for the tactor array, air-cooling over the torso, and applied both low and high pressure against the tactors. Concave-shaped regions of the body, such as the lower back, spine and sternum, required three discrete high-pressure bladders to improve tactor-body contact.

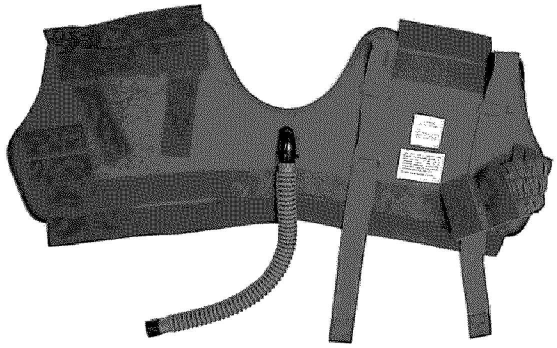

Figure 6 – F-22 air-cooling vest (MSF843)

Anti-Gravity Protection

ATAGS - Magnetic Resonance Imaging

During development of the Advanced Tactical Anti-Gravity Suit (ATAGS), Mustang Survival applied magnetic resonance imaging (MRI) techniques to assess differences in the expansion envelope of inflated anti-G trouser bladders [16]. By wetting the trouser materials with water, the technique was able to image the garment and underlying tissues and bones. MRI proved to be a very effective tool for evaluating various design approaches that would limit ATAGS bladder expansion in regions previously causing cockpit interference.

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